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DEPARTMENT OF THE NAVY
DAVID TAYLOR MODEL BASIN

HYDROMECHANICS

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GRAPHS FOR PREDICTING THE IDEAL HIGH-SPEED RESISTANCE OF PLANING CATAMARANS

by

Eugene P. Clement

HYDROMECHANICS LABORATORY
RESEARCH AND DEVELOPMENT REPORT

November 1961 Report 1573

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NOTATION

A	Aspect ratio, b/l_m
b	Beam of planing surface, ft
C_f	Skin-friction coefficient
C_{LS}	Lift coefficient based on principal wetted area, $\Delta/\frac{1}{2}\rho SV^2$; also, C_{LS} equals $C_{L_L} + C_{L_C}$
C_{L_L}	Lifting line term in expression for C_{LS}
C_{L_C}	Cross-flow term in expression for C_{LS}
C_{Lb}	Lift coefficient based on beam of planing surface, $\Delta/\frac{1}{2}\rho V^2 b^2$
C_{Lp}	Lift coefficient based on center-of-pressure location, $\Delta/\frac{1}{2}\rho V^2 l_{cp}{}^2$
F_∇	Froude number based on volume of water displaced at rest, in any consistent units $V/\sqrt{g\nabla^{1/3}}$
g	Acceleration due to gravity, 32.16 ft/sec^2
l_m	Mean wetted length (distance from aft end of planing surface to the mean of the heavy spray line), ft
l_{cp}	Center-of-pressure location (Measured from aft end of planing surface), ft
$\frac{l_{cp}}{l_m}$	Nondimensional center-of-pressure location
R	Resistance of planing bottom, lb
Re	Reynolds number, $\frac{Vl_m}{\nu}$
S	Principal wetted area (bounded by trailing edge, chines, and heavy spray line), sq ft

V	Horizontal velocity, ft/sec
V_m	Mean water velocity over pressure area, ft/sec
β	Angle of deadrise, deg
ρ	Mass density of water, slugs/ cu ft
τ	Trim (angle between planing bottom and horizontal), deg
ν	Kinematic viscosity, sq ft/sec
Δ	Gross weight (equals planing lift), lb
$\Delta\lambda$	Effective increase in friction area length-beam ratio due to spray contribution to drag
∇	Volume of water displaced at rest, cu ft

ABSTRACT

This report presents graphs by means of which the high-speed resistance and trim of catamaran planing hulls of a wide range of sizes and proportions can be determined. Graphs which give guidance in selecting parameters which will result in optimum planing performance are also presented. Values for the graphs were obtained from equations for the lift, center of pressure, and resistance of prismatic planing bottoms which were previously developed by the National Aeronautics and Space Administration and the David Taylor Model Basin.

INTRODUCTION

Reference 1,* by the National Aeronautics and Space Administration, presented semiempirical equations for the pure planing lift and center of pressure on flat and V-bottom planing surfaces. This reference showed that there was good agreement between results from the equations and data from extensive tests of prismatic planing surfaces. Subsequently, in References 2 and 3, the David Taylor Model Basin presented equations (utilizing the NASA equations for lift and center of pressure) by means of which the resistance of planing hulls at high speeds can be calculated. Comparisons of the calculated values of resistance with values obtained from tests of a model of a representative planing boat have showed good agreement.

Reference 3 presented graphs of lift coefficient, center-of-pressure ratio, and resistance/displacement ratio (R/Δ) for a range of trims, and for values of aspect ratio from 0.3 to about 2.0. The graphs of lift coefficient and center-of-pressure ratio are applicable to boats of any size. The values of R/Δ were computed for a number of gross weights from 1,000 to 100,000 lb. By means of the graphs of Reference 3 it is possible to make estimates of the high-speed resistance and trim of stepless and stepped planing hulls of a wide range of sizes.

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* References are listed on page 9.

Values of C_{LS} were calculated for a range of values of β, τ, and A, using the first equation. These values are presented in the form of the ratio of C_{LS} to τ (in degrees) in Figure 1. Presentation of the lift coefficient data in this form, rather than in the usual form of C_{LS} versus τ, results in graphs which yield greater accuracy when the graphs are used for making performance predictions.

Values of l_{cp}/l_m were calculated using the second of the above equations, and are plotted as ordinates in Figure 2, with the ratio l_{cp}/b as abscissa. The values of l_{cp}/b were determined from the selected values of aspect ratio, and the calculated values of l_{cp}/l_m, by means of the relationship:

$$\frac{l_{cp}}{b} = \frac{l_{cp}}{l_m} \cdot \frac{l_m}{b} = \frac{l_{cp}}{l_m} \cdot \frac{1}{A}$$

Equations from which the resistance can be calculated were developed in Reference 2. The final equations are as follows:

$$R/\Delta = \tan \tau + \frac{C_f}{C_{LS}} \left[\left(\frac{V_m}{V} \right)^2 + A \Delta \lambda \right]$$

C_{LS} is given by the first equation in the report, and C_f is given as a function of Reynolds numbers by the 1947 ATTC friction formulation, as follows:

$$\frac{0.242}{\sqrt{C_f}} = \log_{10} \text{Re} \cdot C_f$$

Reynolds number is given by

$$\text{Re} = \frac{1}{\nu} \cdot \sqrt{\frac{2 \Delta \cos \beta}{C_{LS} \quad A} \left(1 - \frac{C_{LS}}{\cos \tau \cos \beta}\right)}$$

Both a mathematical expression for, and a graph of, $\Delta\lambda$ are given in Reference 4. An expanded version of the graph is presented in Figure 7. The negative values of $\Delta\lambda$ correspond to the case where the velocity of the spray has a forward component with respect to the planing bottom, and therefore tends to reduce rather than increase the drag. However, for 0-degree

deadrise the calculated value of $\Delta\lambda$ is $-\infty$, which yields a calculated value of R/Δ also equal to $-\infty$. In order to avoid this absurd result the value of $\Delta\lambda$ in the calculation of R/Δ was arbitrarily taken to be zero when the calculated value of $\Delta\lambda$ was negative. The practical effect of this assumption is that the values of R/Δ presented in this report for 0-degree deadrise may be slightly conservative (i.e., slightly high).

Values of R/Δ were calculated for a range of values of β, τ, and A (as was the case for the calculations of C_{LS} and l_{cp}/l_m). However, the ratio of resistance to displacement is a function not only of β, τ, and A, but also of the gross weight, Δ. Therefore, values of R/Δ were calculated for gross weights of 1000, 5000, 10,000, 50,000, and 100,000 lb. The values of R/Δ for a gross weight of 10,000 lb are presented in Figure 3. These curves will be put to further use later in the report. The values of R/Δ for the range of gross weights from 1000 to 100,000 lb are presented in Figures 4, 5, and 6.

SAMPLE PERFORMANCE PREDICTION

Values of the ideal resistance and the trim angle of a planing catamaran at several speeds in the planing region can be readily estimated by means of the graphs which have been presented. The following example illustrates the process of estimating the performance of a typical boat. The dimensions assumed are as follows:

Displacement = 13,000 lb

Length of boat = 30 ft

Maximum beam over spray strips of one pontoon (b) = 3.0 ft

Average deadrise angle for after-half of length (β) = 10 deg

Distance of c.g. forward of transom (l_{cp}) = 13.0 ft

R/Δ is determined for one pontoon, using the beam and the load carried by one pontoon (6,500 lb).

The numbered columns below indicate the sequence of the process of determining the planing performance:

1	2	3	4	5	6	7	8	9	10	11	12
τ, deg	$\frac{l_{cp}}{l_m}$	A	R/Δ	R, lb	$\frac{C_{LS}}{\tau^o}$	C_{LS}	$S_{\cdot} = b^2/A$	$\frac{6,500}{SC_{LS}}$	V, fps	V, knots	F_∇
1.0	.838	.193	.515	6695	.0041	.0041	46.6	34,010	184.4	109.2	13.41
1.5	---	---	---	----	----	----	----	------	-----	-----	-----
2.0	.806	.186	.261	3395	.00435	.0087	48.5	15,400	124.1	73.5	9.03
2.5	---	---	---	----	-----	----	----	------	-----	----	----
3.0	.779	.180	.193	2510	.00465	.01395	50.0	9,320	96.5	57.2	7.02
3.5	---	---	---	----	-----	-----	----	-----	----	----	----
4.0	.754	.174	.169	2195	.0049	.0196	51.7	6,410	80.1	47.4	5.82
4.5	---	---	---	----	----	----	----	-----	----	----	----
5.0	.733	.169	.162	2105	.0052	.0260	53.2	4,700	68.6	40.6	4.99

First a number of trim angles are assumed and entered in Column 1. Next, the ratio l_{cp}/b is determined. This is:

$l_{cp}/b = 13.0/3.0 = 4.33.$

Then values of the ratio l_{cp}/l_m for the different trim angles are read from Figure 2(c) and entered in Column 2. The values of l_{cp}/l_m are then divided by the constant value of l_{cp}/b to give the aspect ratio. These values are entered in Column 3. Next, values of R/Δ are read from Figure 6, and entered in Column 4. Then, multiplying the values of R/Δ by the boat displacement (13,000 lb) will give the boat resistance in pounds. These values have been entered in Column 5.

The resistance is now known, and the remaining calculations are for the purpose of determining the corresponding values of speed. The speed is determinined by solving for V in the expression $C_{LS} = \Delta/\frac{1}{2}\rho SV^2$. $\frac{1}{2}\rho$ is assumed equal to 1. Then $V^2 = \Delta/C_{LS}S$.

Values of C_{LS}/τ are read from Figure 1(c) and entered in Column 6. Multiplying by τ in degrees gives C_{LS} which is entered in Column 7. Next

S is calculated from the relationshp $S = b^2/A$ and entered in Column 8. The quantity $6{,}500/SC_{LS}$ is then computed and entered in Column 9. The square root of Column 9 gives the velocity in feet per second (Column 10). Speed in knots has been entered in Column 11, and the dimensionless speed coefficient F_∇ in Column 12.

The graphs which are presented in this report will give valid predictions of the performance of individual hulls in the planing region, where most of the load is supported by dynamic lift. However, they do not give accurate predictions of performance at speeds where an appreciable portion of the load is supported by buoyancy. Furthermore, it is important to note, for the case of planing catamarans, that it is not at present possible to calculate the interference effects of the spray or waves from one hull on the other, and accordingly these effects are not included.

CALCULATED PERFORMANCE OF THREE PLANING CATAMARANS

In addition to the automatic computer program which was developed for the purpose of calculating the values of lift coefficient, etc., which are presented in Figures 1 through 6, a program was also developed which would give values of resistance and trim for specific planing boat designs for a number of speeds in the planing range. The basic equations utilized were the same as for the previous program (i.e., the basic equations used were those presented heretofore in this report).

This second program was used to calculate values of resistance and trim for three catamaran designs and also, for comparison purposes, for a conventional planing hull. The items assumed for the purpose of the calculations were as follows:

Δ is 10,000 lb; distance of L.C.G. forward of transom is 11.4 ft. Salt water assumed at 59°F; zero roughness allowance. Deadrise angle is 10° for the conventional hull and 5° for the three catamarans. Maximum width over the chines for the conventional hull is 9 ft, and maximum bottom width of a single pontoon for the three catamarans is 3 ft, 2 ft, and 1 ft, respectively.

The calculated values of resistance and trim for the four designs are plotted against speed coefficient in Figure 8. In addition, the variation of aspect ratio with speed was determined for the four designs, and is also included in Figure 8. (The same curves could have been developed by means of Figures 1, 2, 5 and 6 of this report.) The trend of the curves indicates that the conventional hull has the least resistance up to a speed coefficient of about 4.6. At a speed coefficient of 6, however, both the catamaran with the 3-ft wide pontoons and the catamaran with the 2-ft wide pontoons has considerably less resistance than the conventional hull. At a speed coefficient of 7, the catamaran with the 2-ft wide pontoons has the least resistance.

This finding that the ideal catamaran resistance at very high speeds is considerably less than the resistance of a conventional planing boat was quite unexpected because of the obvious fact that the conventional planing boat has much the higher aspect ratio. Some light is shed on the situation, however, by considering the important part played by the trim angle. The performance data of Figure 8 show that as the speed increases, the trim angle of each of the designs decreases markedly, while their individual values of aspect ratio change only slightly. Also, it can be seen that at any given speed the trim angle for the conventional planing boat is considerably below the trim angles for any of the catamaran hulls. At a speed coefficient of 7, for example, the trim angle for the conventional hull is about 1° and its value of aspect ratio is about 0.68. Figure 3(c) clearly shows that this operating condition necessarily falls in a region of very high resistance. Now consider the operating condition of the catamaran with the 2-ft wide pontoons at the same value of speed coefficient. The trim angle for this case will be 4.2°, and the value of aspect ratio will be 0.13. Examination of Figure 3(b) shows that this operating condition gives a value of resistance only slightly above the minimum resistance for this particular value of aspect ratio. To summarize, the reason that the ideal resistance of a planing catamaran at very high speeds is considerably lower than the resistance of a conventional planing boat (in spite

of the fact that the conventional planing boat has much the higher aspect ratio) results from the fact that the conventional hull will operate at a very flat trim angle and, accordingly, in a region of very high resistance, while the catamaran hull will assume a higher trim angle which is much closer to its angle for minimum resistance.

The boat sizes assumed for the above comparison are quite large, but the same considerations would apply even in the case of small outboard motorboats. Accordingly, the above discussion is believed to be the appropriate explanation for the quite striking successes which have been achieved by outboard-powered catamarans in racing competitions against hulls of conventional form. (The explanation sometimes given in the popular press for the superior performance of the catamaran - its "aerodynamic lift" - is therefore believed to be incorrect.)

CATAMARAN HULLS OF OPTIMUM PERFORMANCE

The curves of Figures 1 through 3 have been used to construct some auxiliary graphs which provide guidance for solving planing catamaran design problems. It can be seen that there is a minimum-resistance point on each of the curves of Figure 3. These minimum-resistance values have been plotted in Figure 9 as a function of aspect ratio. R/Δ has been inverted, however, to give Δ/R, or lift/drag ratio. The values of τ corresponding to the minimum-resistance points are also plotted in Figure 9.

Several auxiliary functions are also plotted in Figure 9, by means of which a number of interesting design problems can be solved. Two of these functions are forms of the lift coefficient. One is C_{Lb}, which equals $\Delta/\frac{1}{2}\rho V^2 b^2$, and the other is C_{Lp}, which equals $\Delta/\frac{1}{2}\rho V^2 l_{cp}{}^2$. There is a unique value of each of these functions for each of the associated pairs of values of aspect ratio and τ which correspond to the minimum-resistance points of Figure 3. The steps involved in obtaining the values for preparing Figure 9 are indicated in Table I of Reference 3. The auxiliary graphs of Figure 10 were drawn in order to obtain the values of l_{cp}/l_m needed for the calculation of C_{Lp}. The values of l_{cp}/b and C_{LS} corresponding to the minimum-resistance condition are also plotted in Figure 9.

One of the design problems which can be solved by means of Figure 9 is the determination of the width of a planing bottom which will give minimum resistance when the weight, speed, deadrise, and distance of the center of gravity forward of the transom are known. From the known quantities, the value of C_{Lp} can be calculated (the distance of the center of gravity forward of the transom is identical to l_{cp}). Figure 9 can then be entered with this value of C_{Lp} and the corresponding value of l_{cp}/b determined (this is the value at the same aspect ratio). The value of the beam, b, can now be calculated. This procedure will be found to be a useful guide in selecting the width of each of the pontoons of a planing catamaran. In this case, of course, the weight to be used in the calculation is the weight carried by one pontoon.

If the ratio l_{cp}/b is known for a design, together with the weight, deadrise, and speed, Figure 9 can be entered, and b then calculated from the corresponding value of C_{Lb}.

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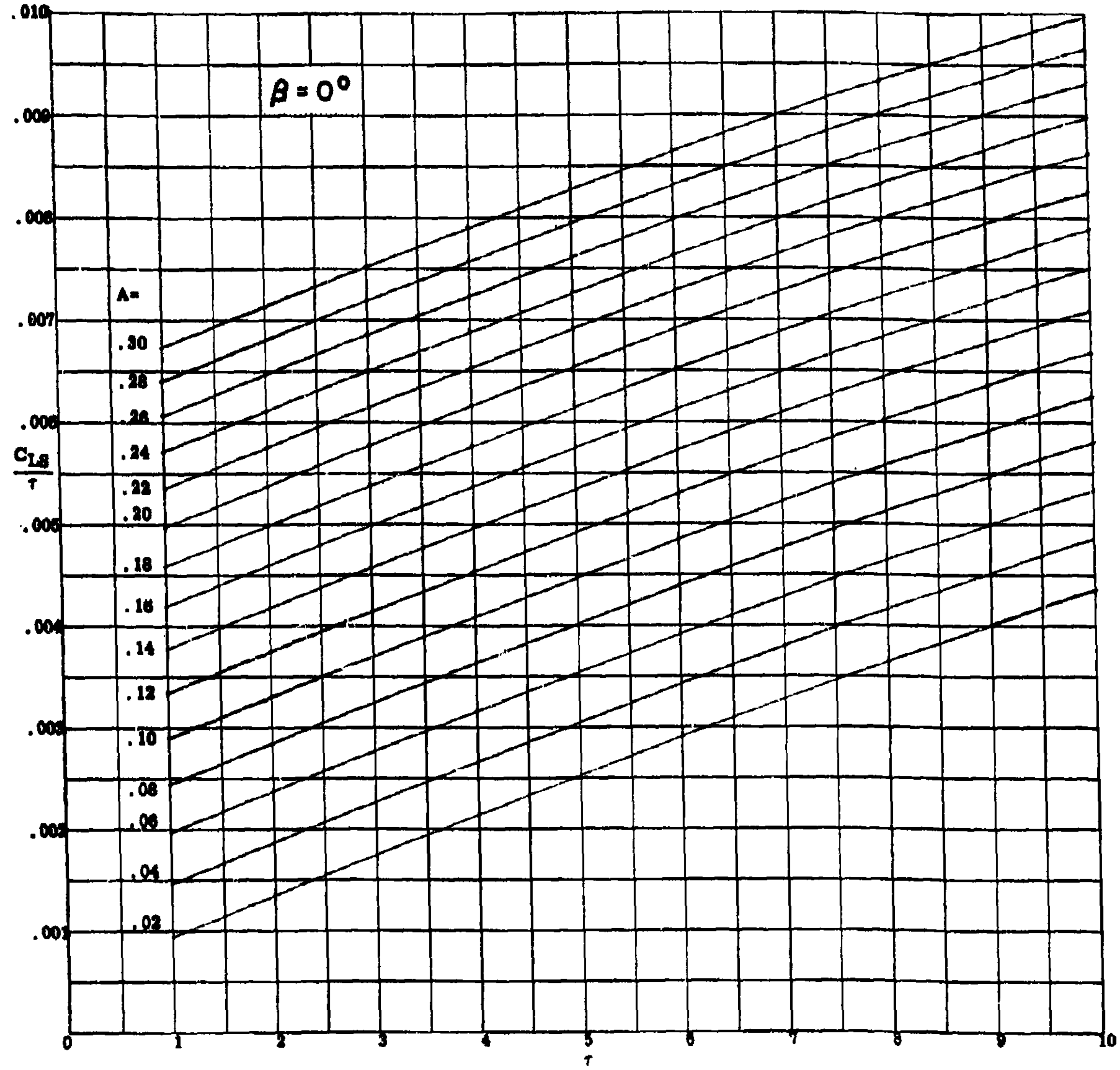
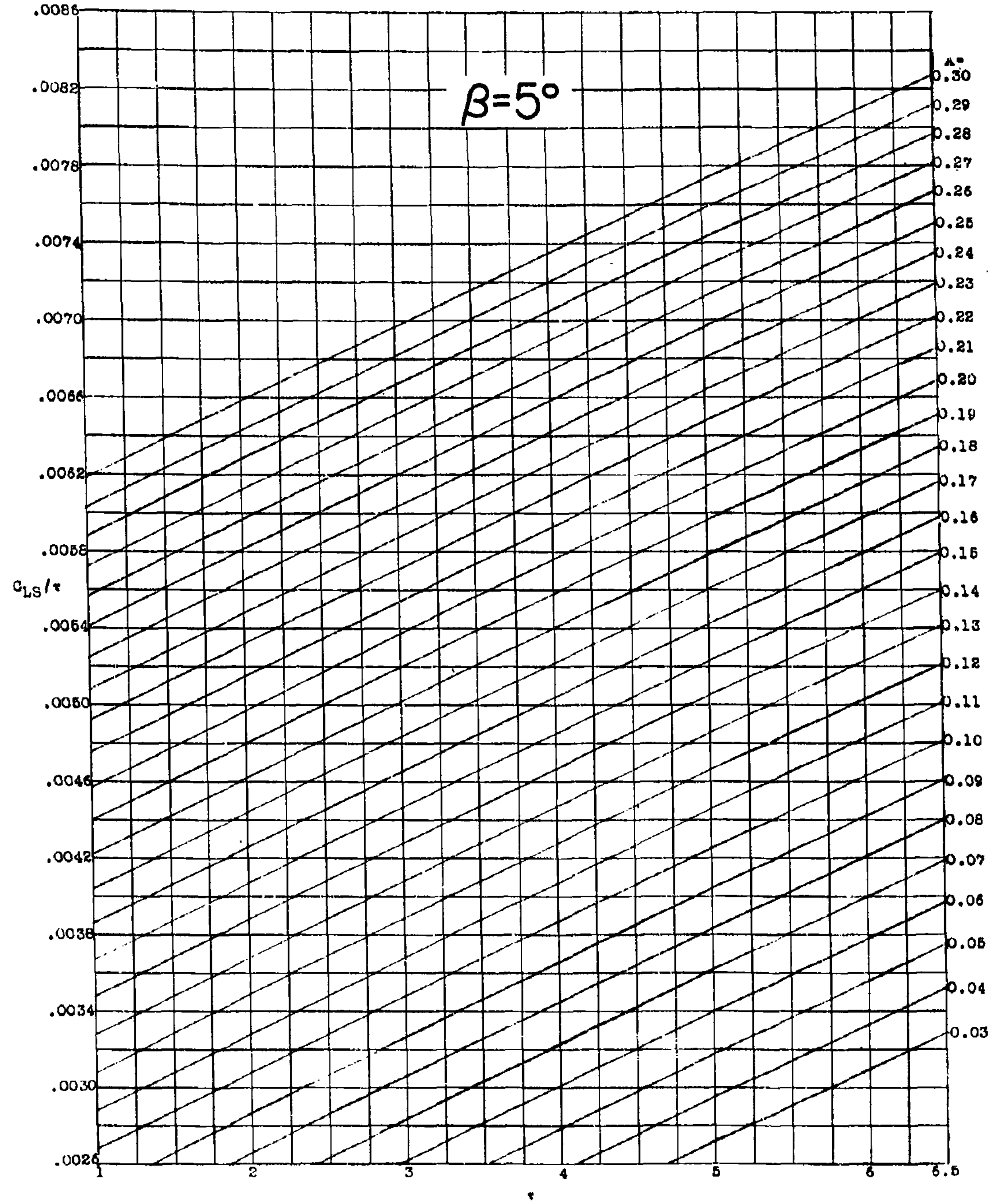
3. Clement, E.P. and Pope, J.D., LTJG, USN, "Stepless and Stepped Planing Hulls - Graphs for Performance Prediction and Design," David Taylor Model Basin Report 1490 (Jan 1961).

4. Savitsky, D. and Ross, E.W., "Turbulence Stimulation in the Boundary Layer of Planing Surfaces - Part II - Preliminary Experimental Investigation," Report 444, Experimental Towing Tank, Stevens Institute of Technology (Aug 1952).



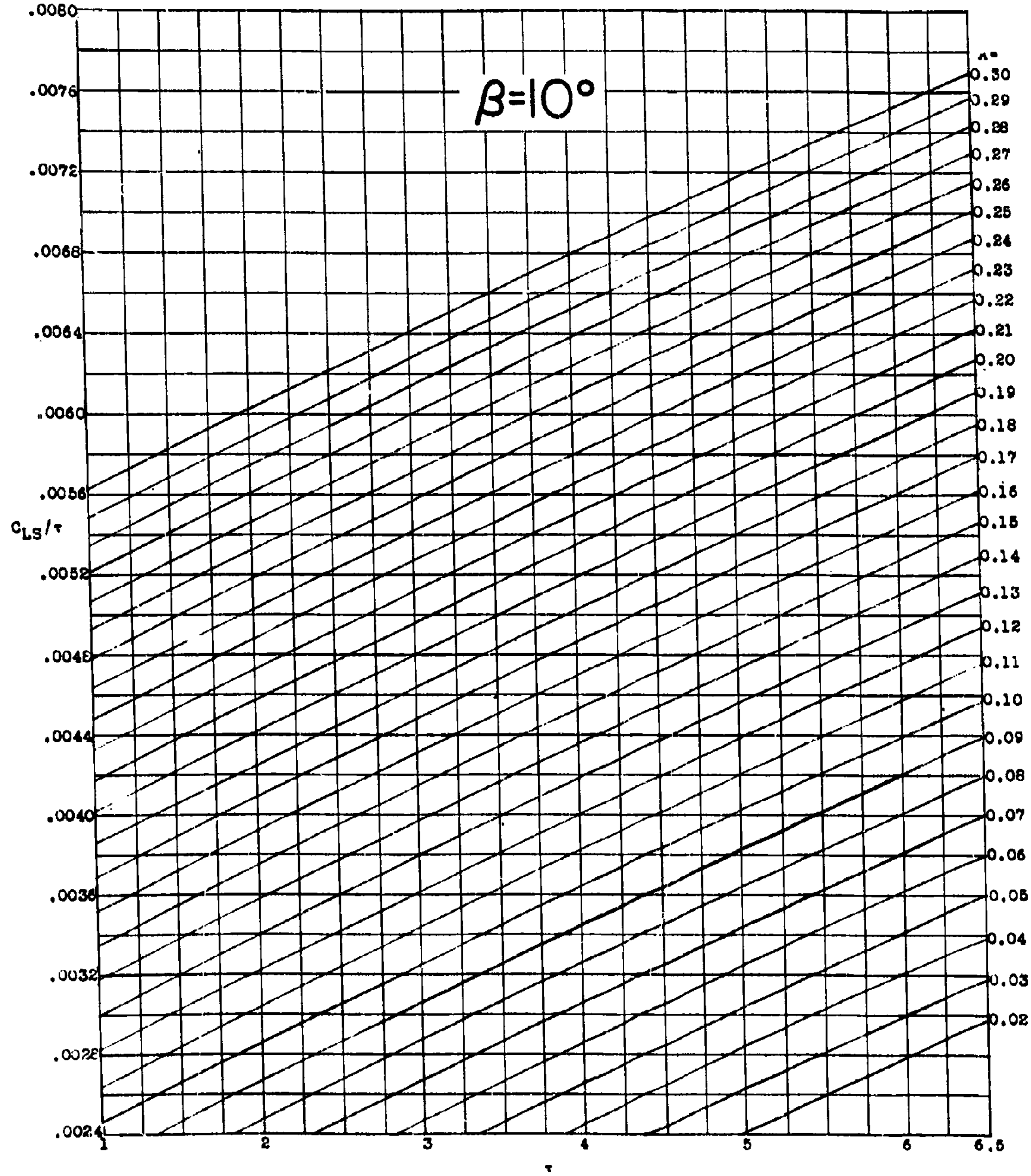
(a) $\beta = 0°$

Figure 1 - Lift-Coefficient/Trim-Angle Ratio, Versus Trim Angle



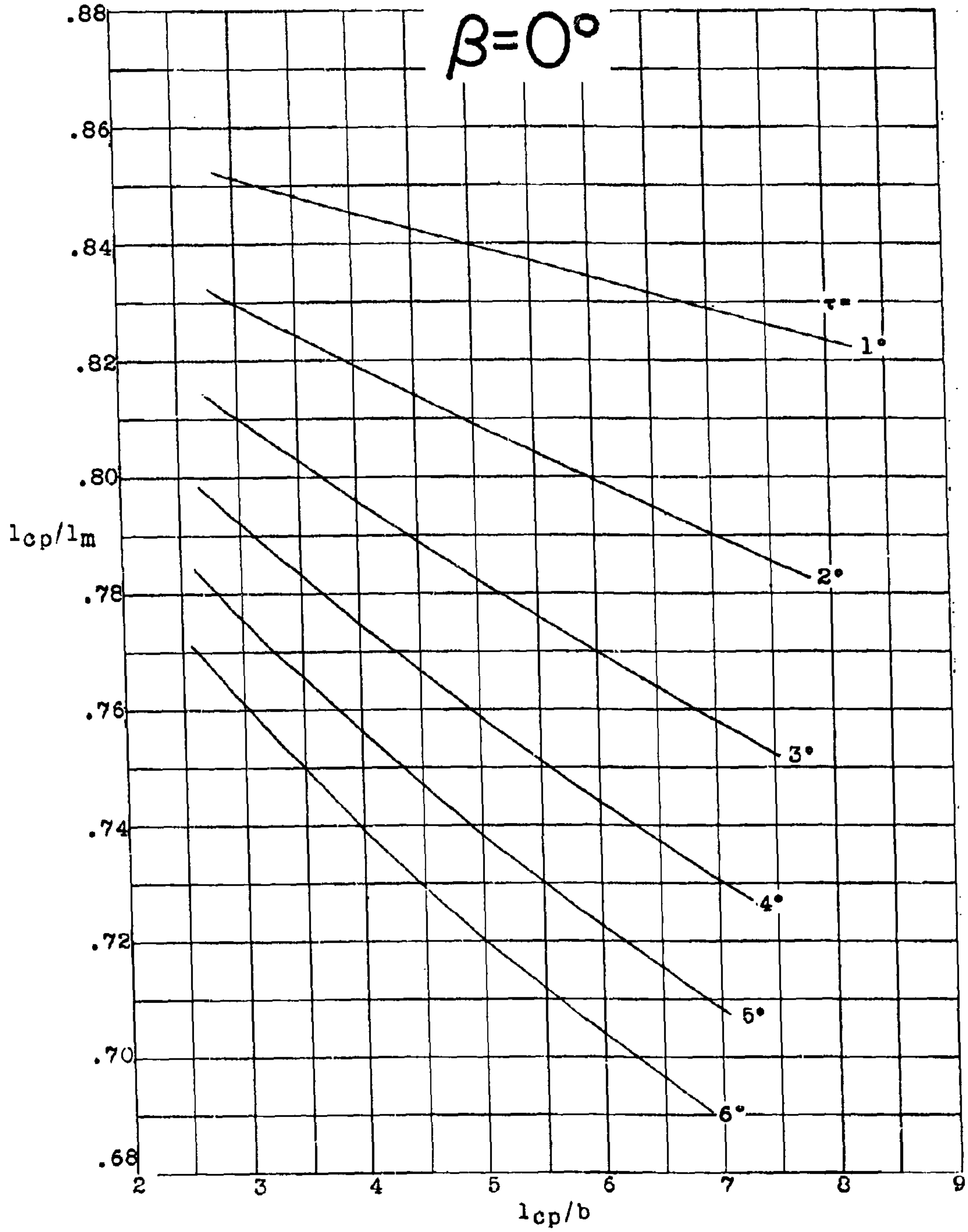
(b) β = 5°

Figure 1 - Continued.



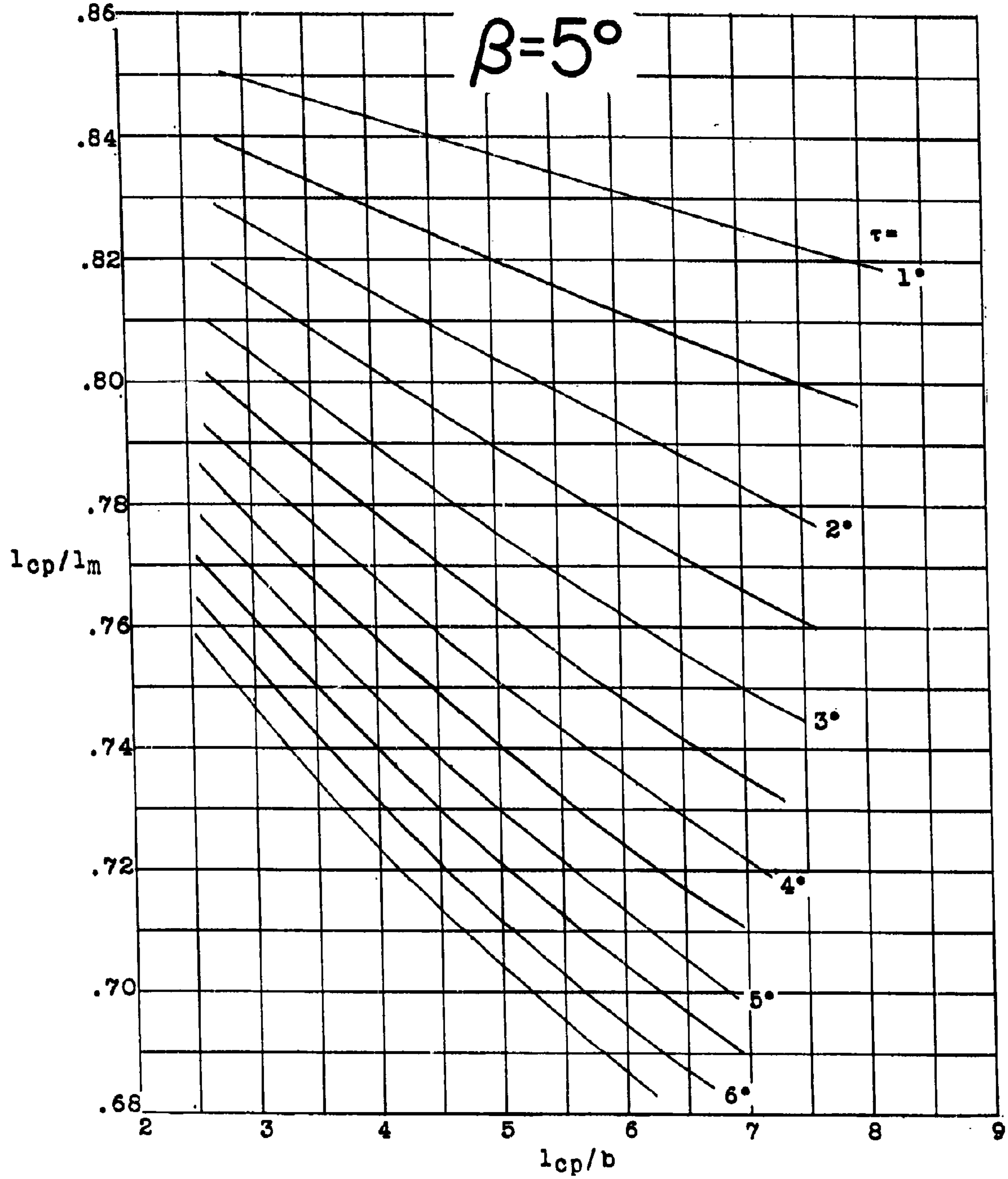
(c) β = 10°

Figure 1 - Concluded.

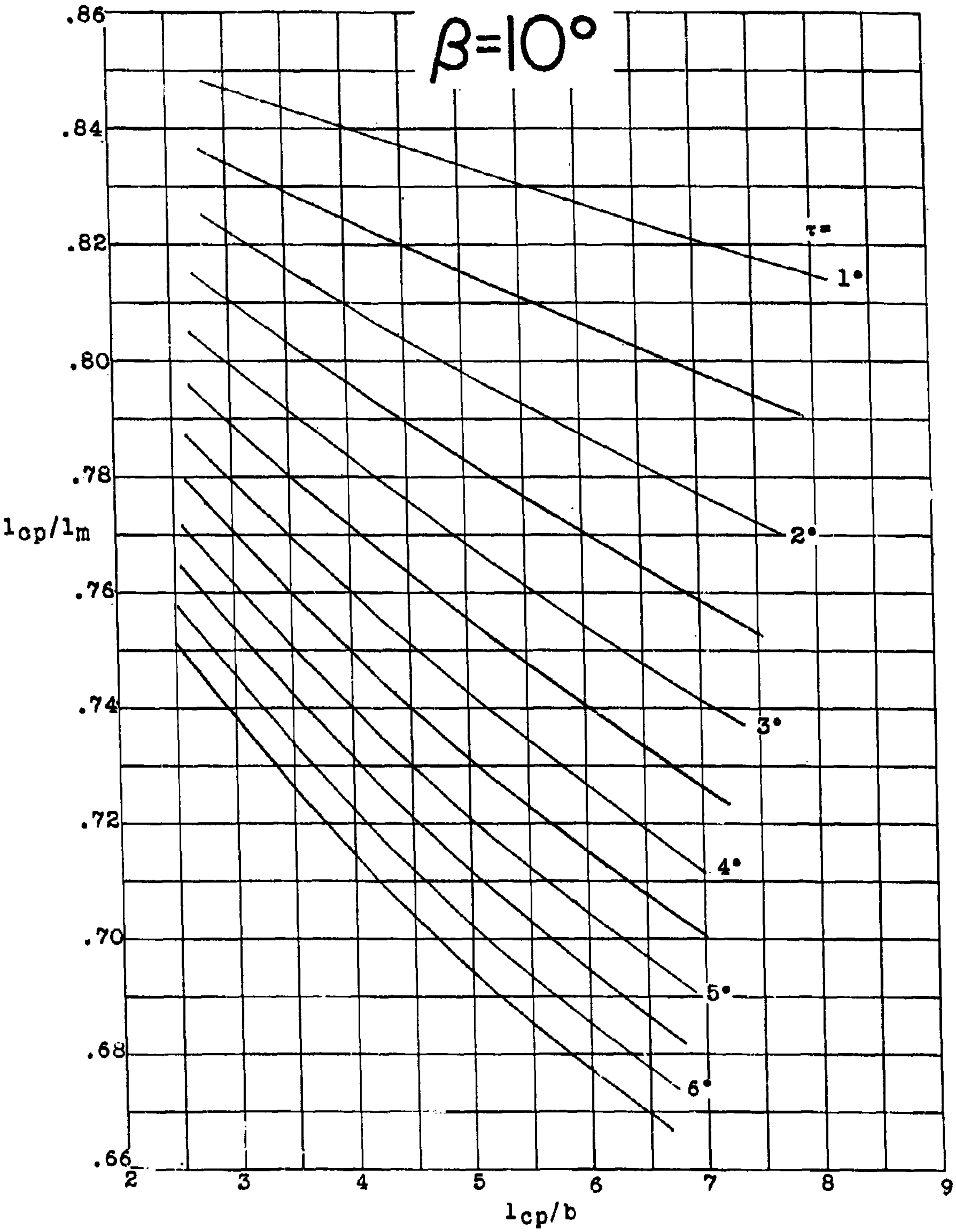


(a) β = 0°

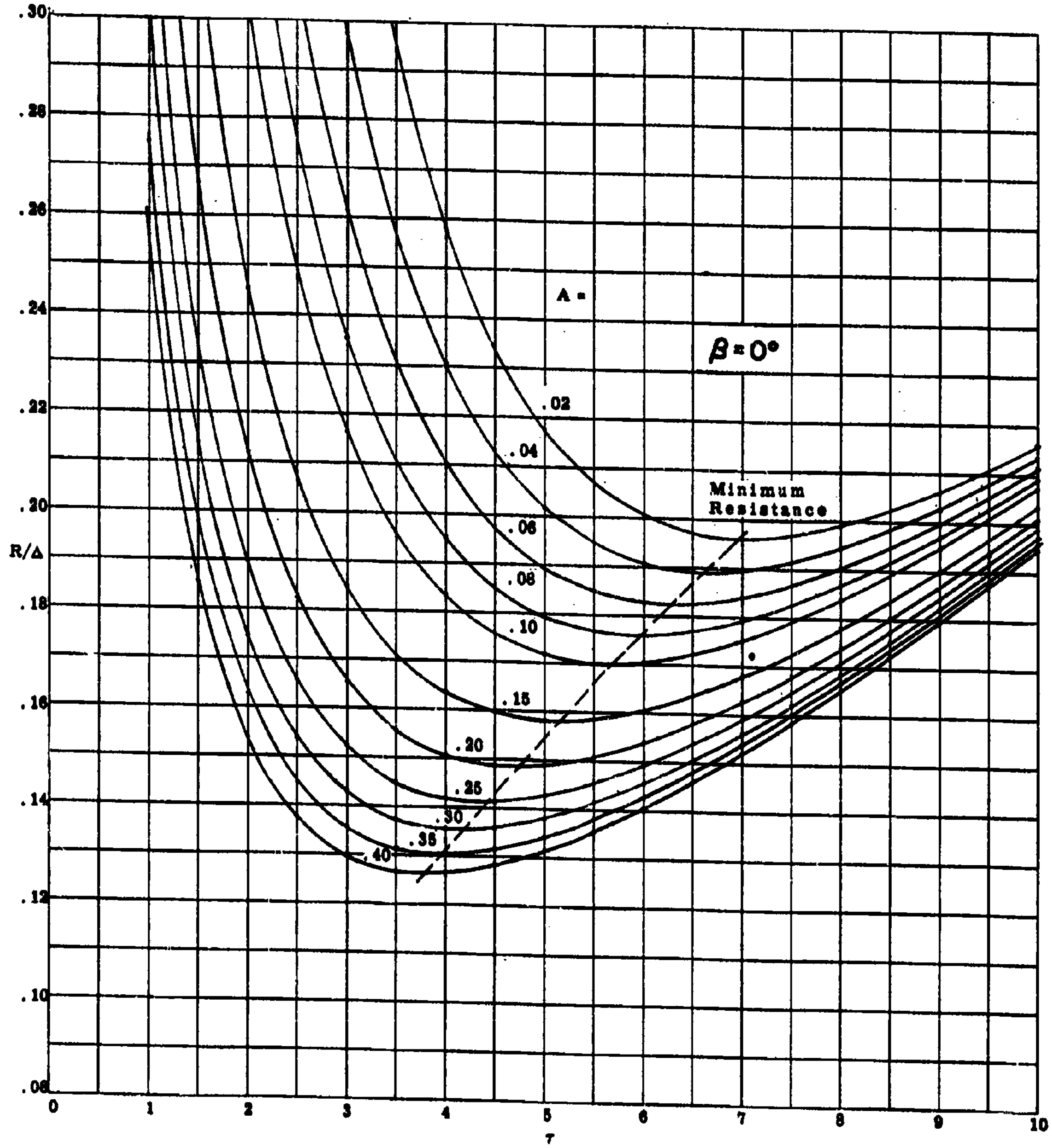
Figure 2 - Center-of-Pressure/Mean-Wetted-Length Ratio, Versus Center-of-Pressure/Beam Ratio.



(b) $\beta = 5°$
Figure 2 - Continued.

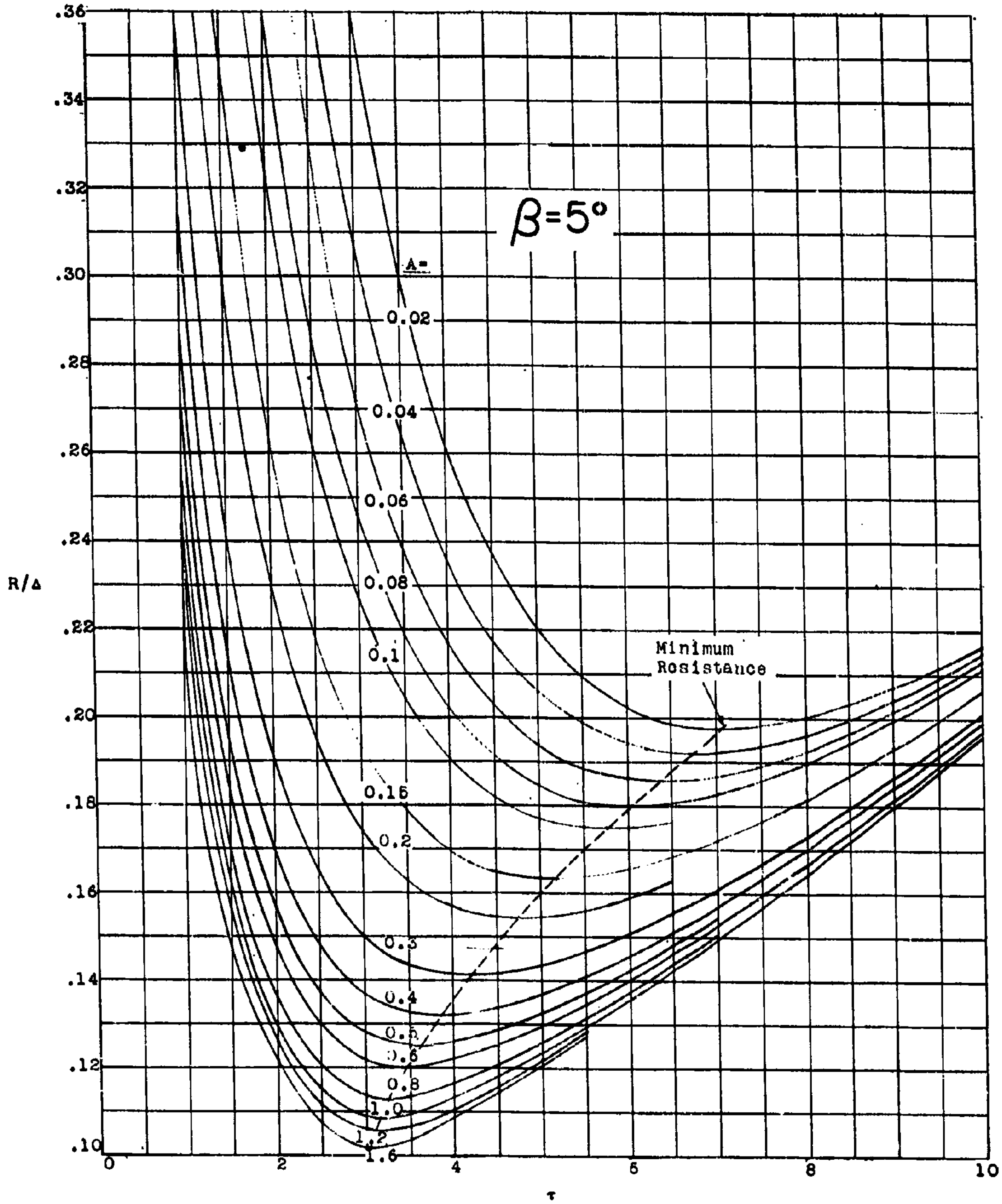


(c) β = 10°
Figure 2 - Concluded.



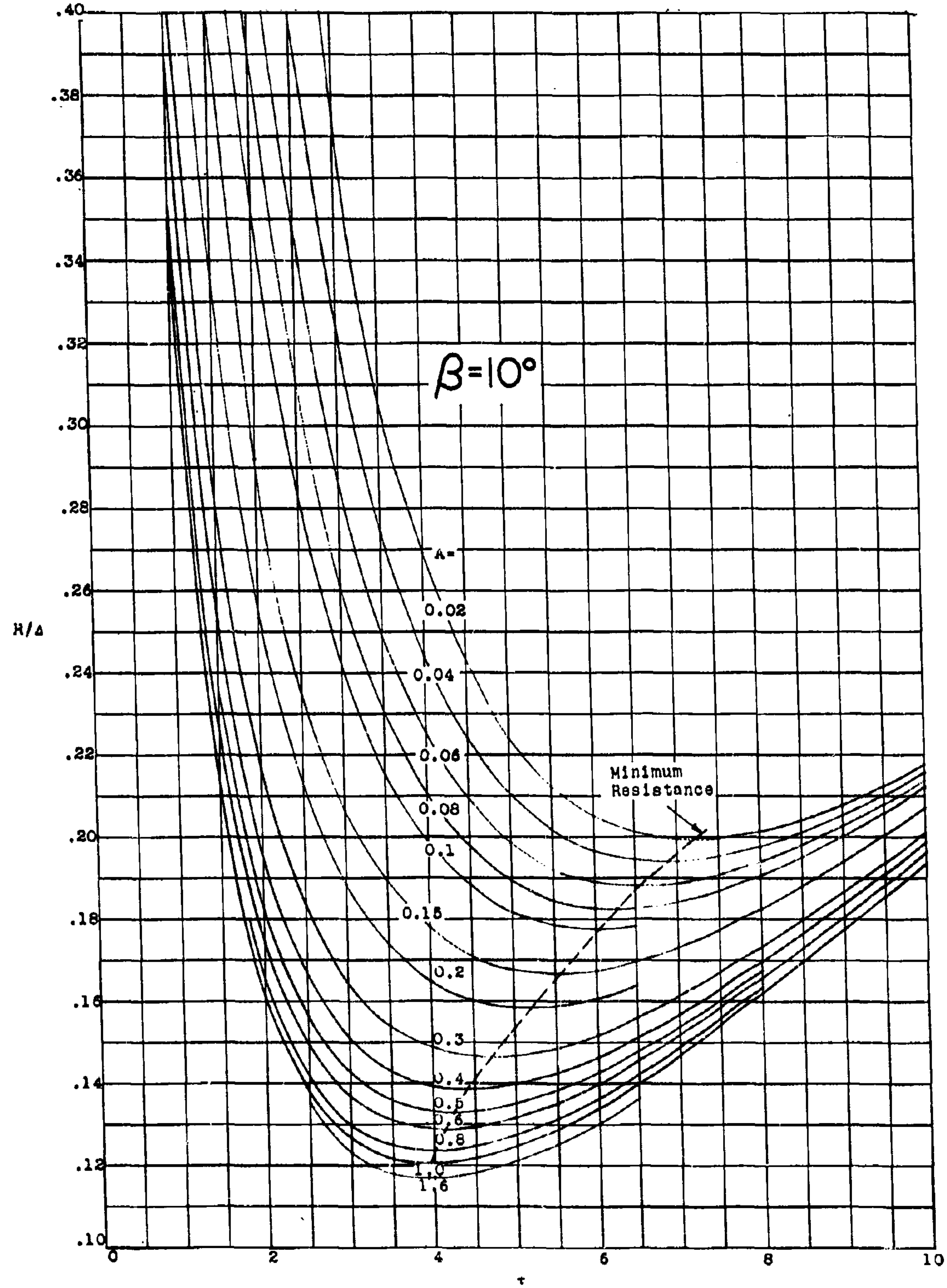
(a) β = 0°

Figure 3 - Resistance/Weight Ratio Versus Trim Angle.
10,000 lb Displacement, Salt Water at 59°F



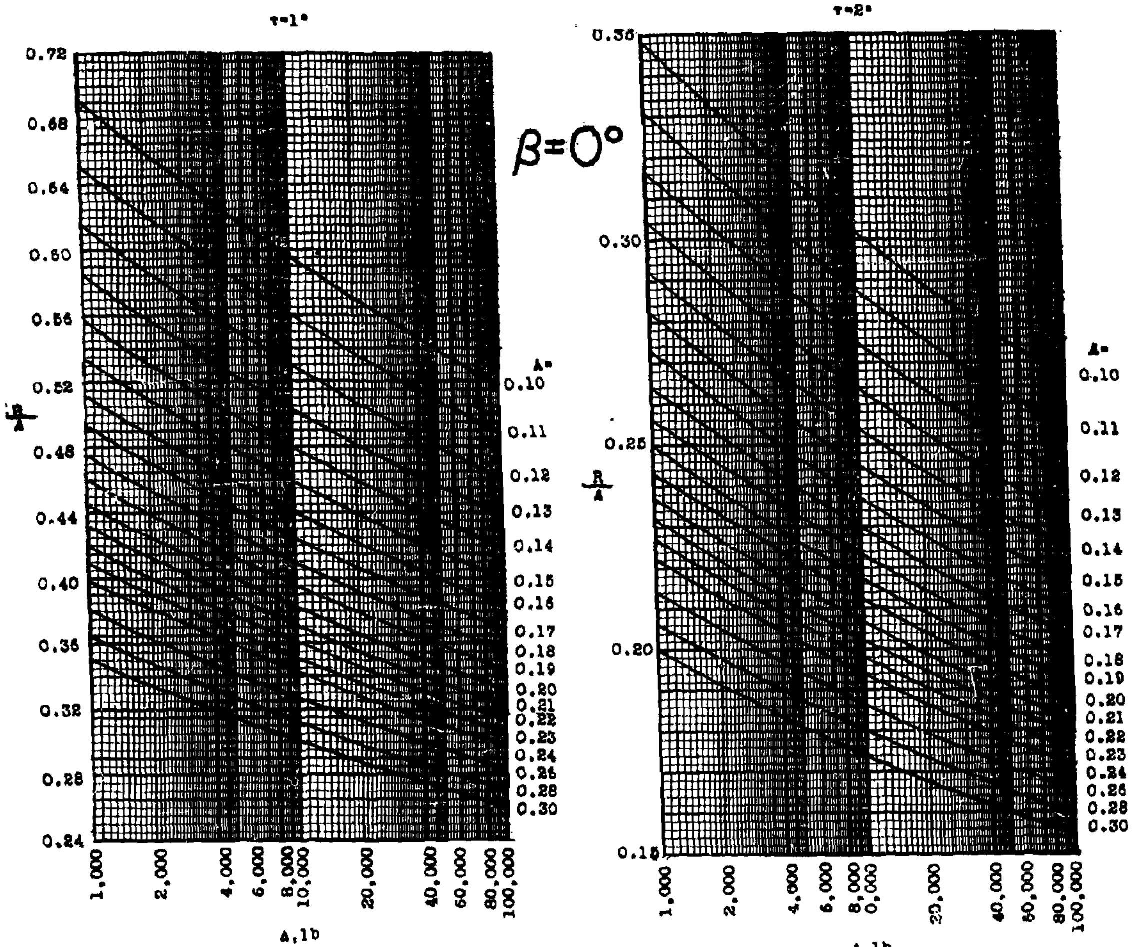
(b) $\beta = 5°$

Figure 3 - Continued



(c) β = 10°

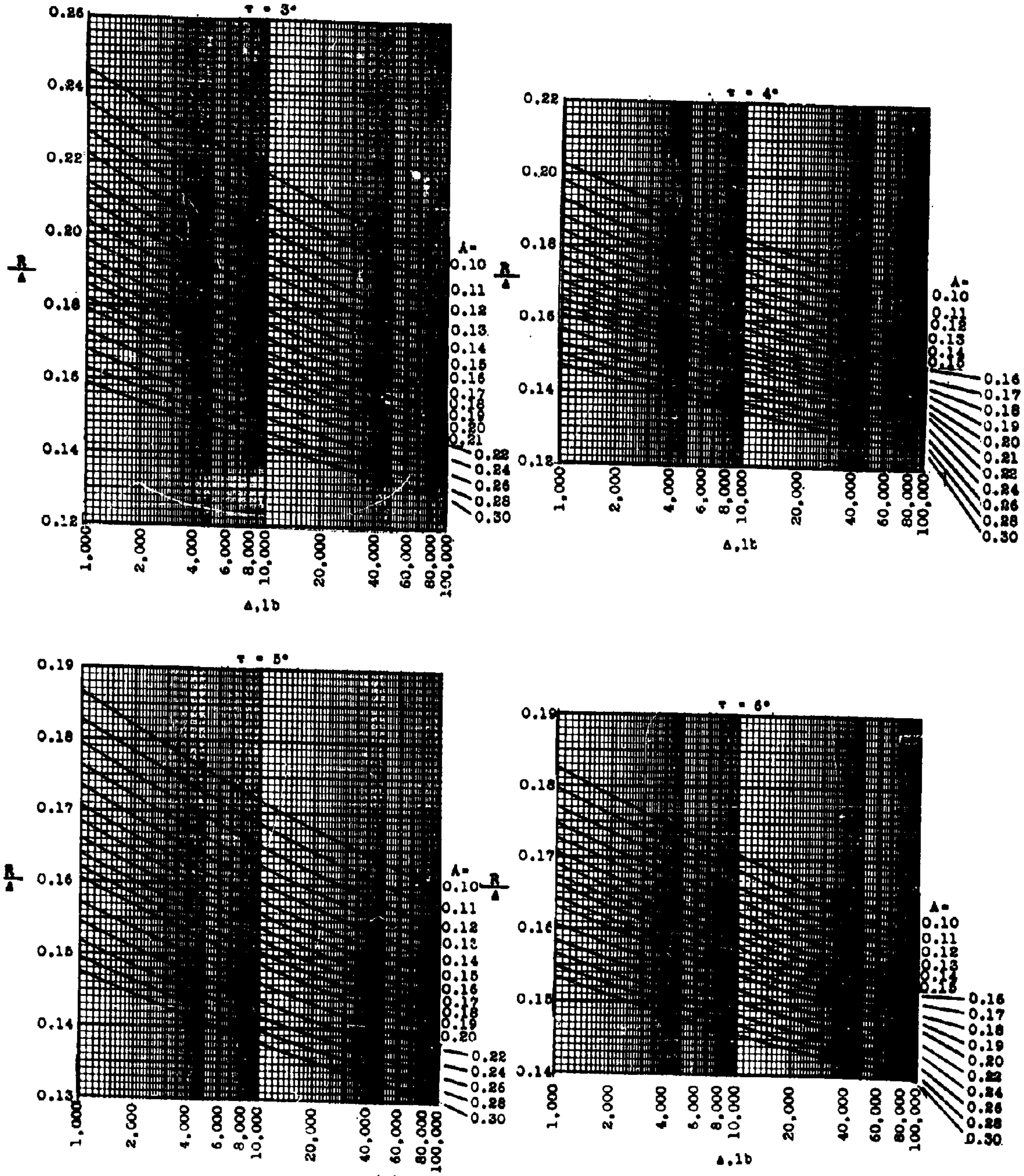
Figure 3 - Concluded



(a) τ = 1° and 2°

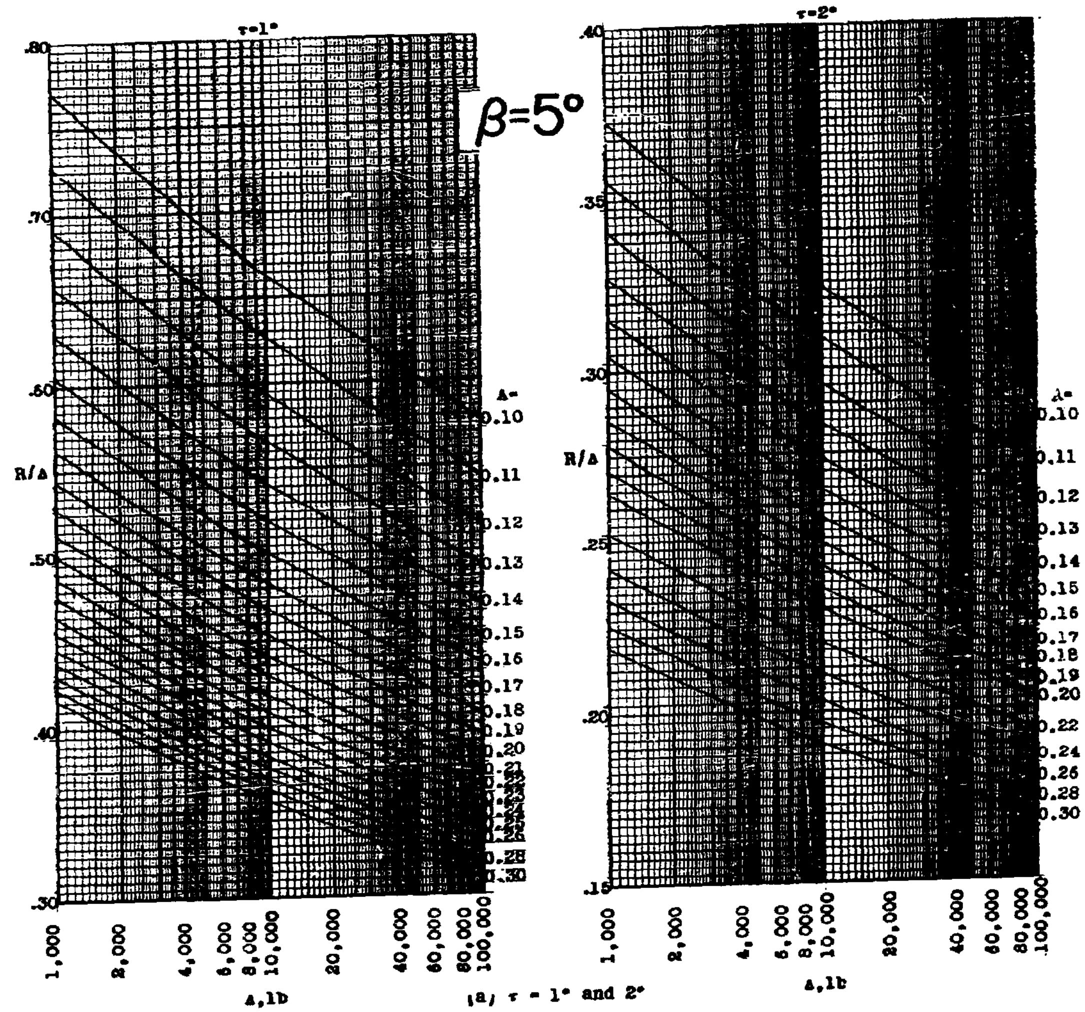
Figure 4 - Resistance/Weight Ratio Versus Weight. β = 0°

$\beta = 0°$



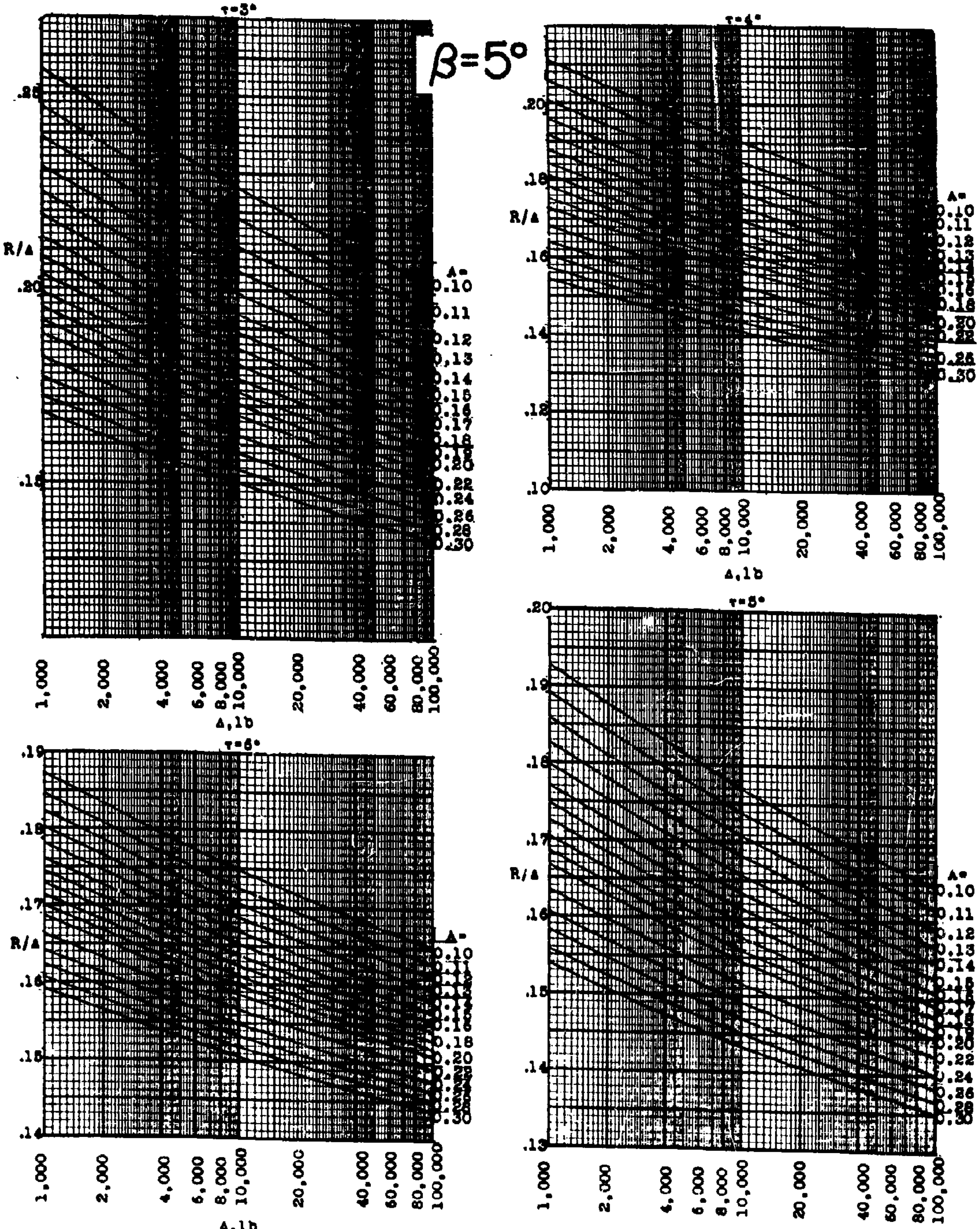
(b) τ = 3°, 4°, 5°, and 6°

Figure 4 - Concluded



(a) τ = 1° and 2°

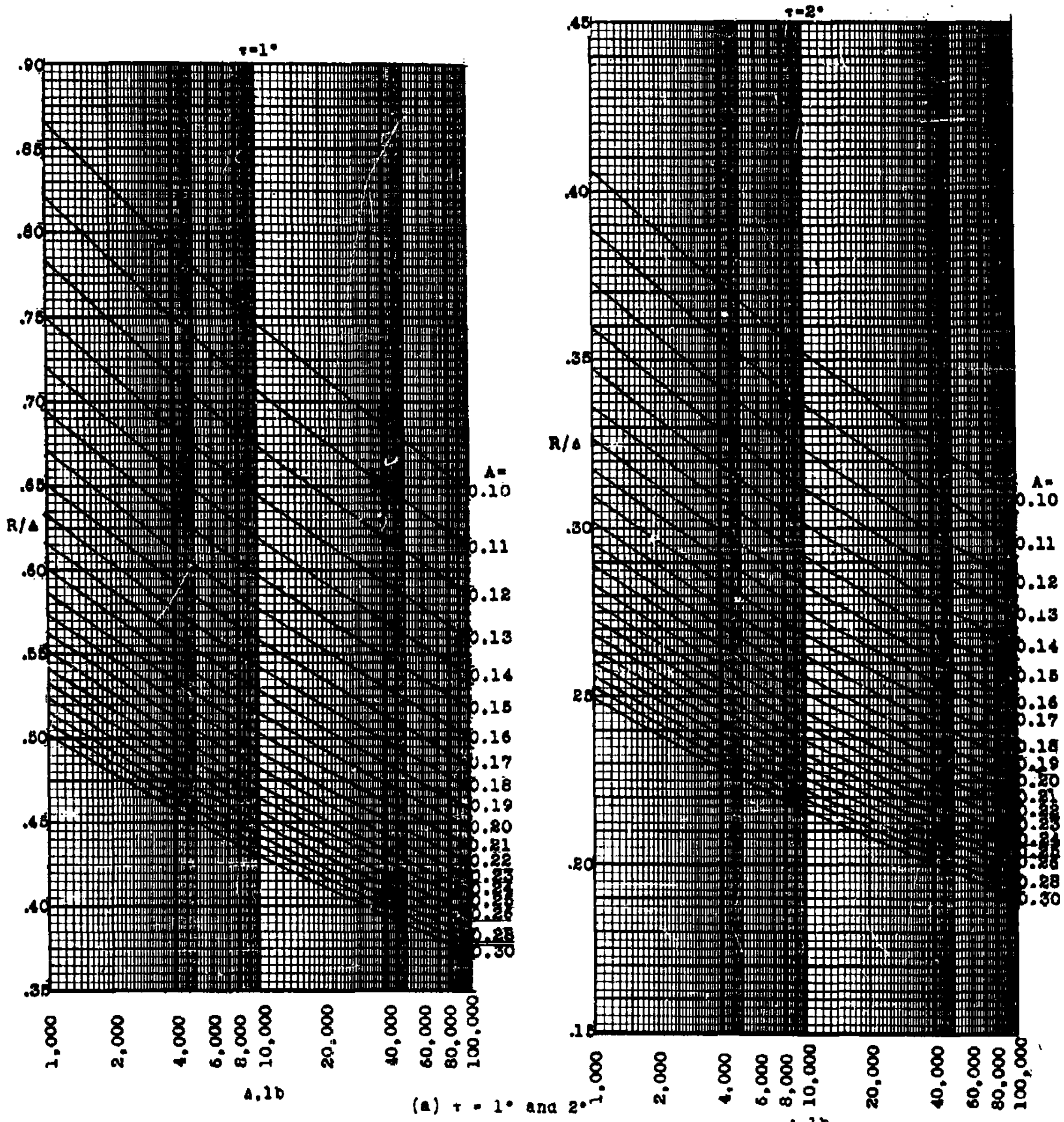
Figure 5 - Resistance/Weight Ratio Versus Weight. β = 5°



(b) τ = 3°, 4°, 5°, and 6°

Figure 5 - Concluded

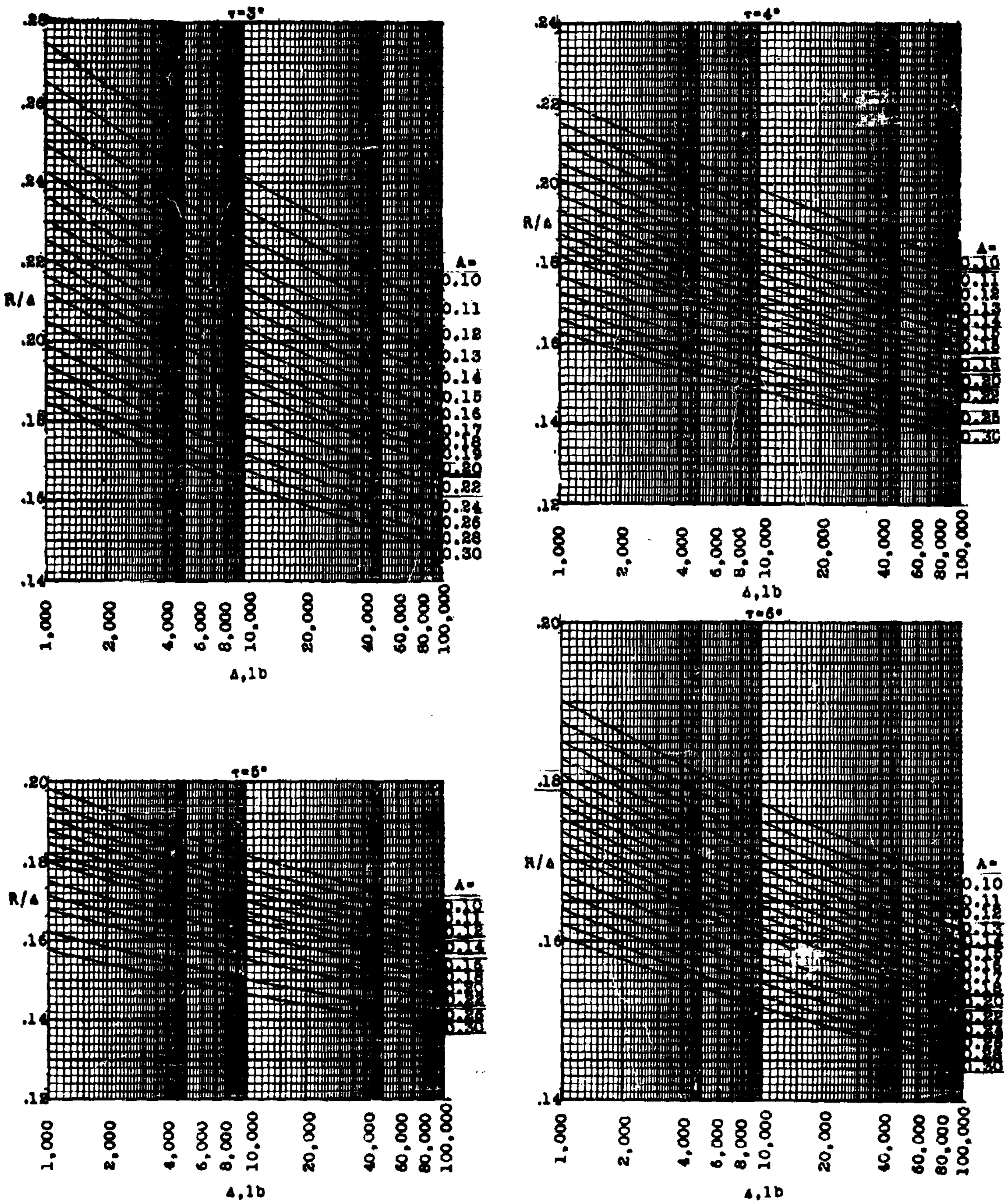
β=10°



(a) τ = 1° and 2°

Figure 6 - Resistance/Weight Ratio Versus weight. β = 10°

β=10°



(b) τ = 3°, 4°, 5°, and 6°

Figure 6 - Concluded

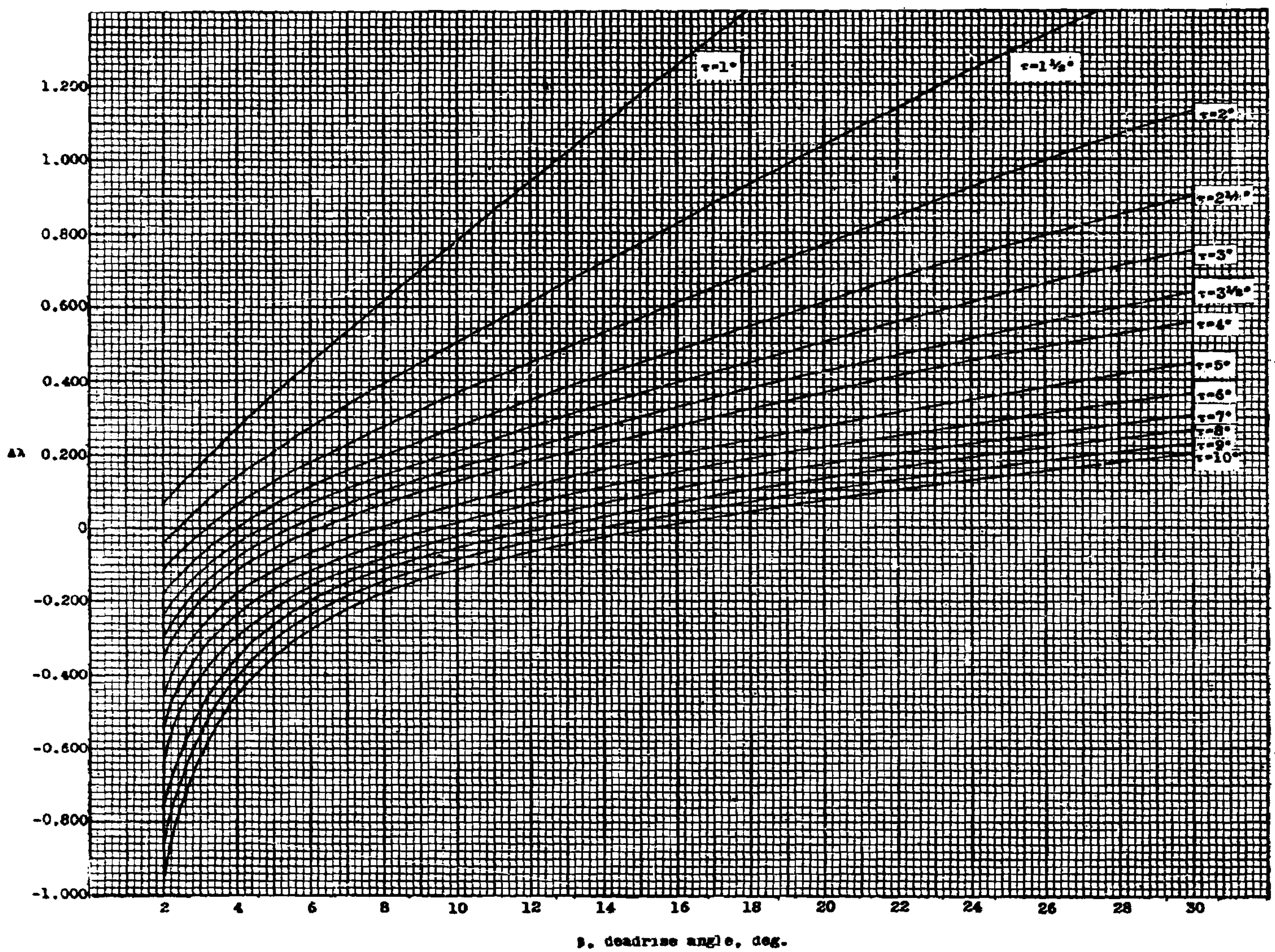


Figure 7 - Effective Increase in Friction-Area Length-Beam Ratio (Δλ) Due to Spray Contribution to Drag

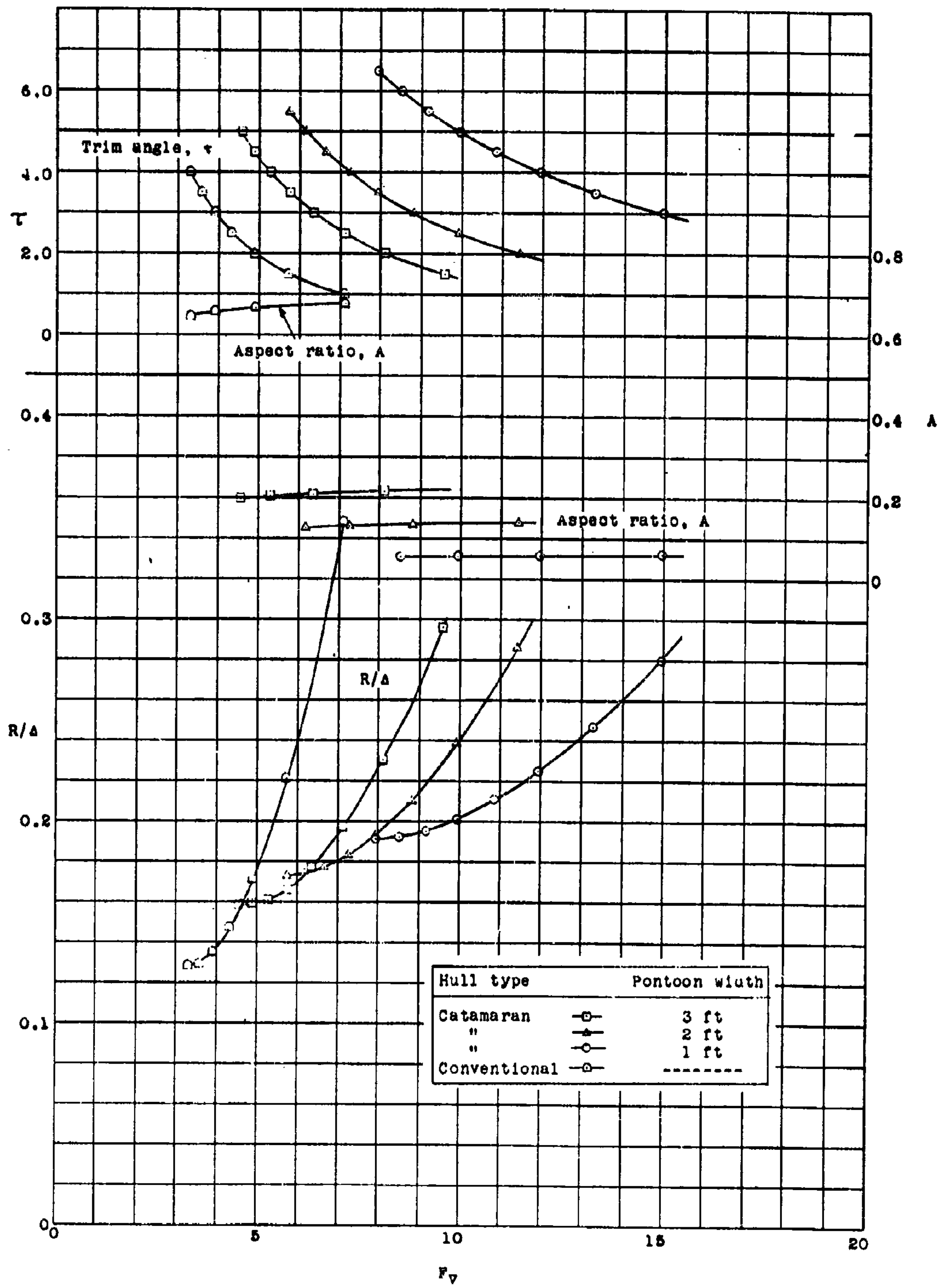
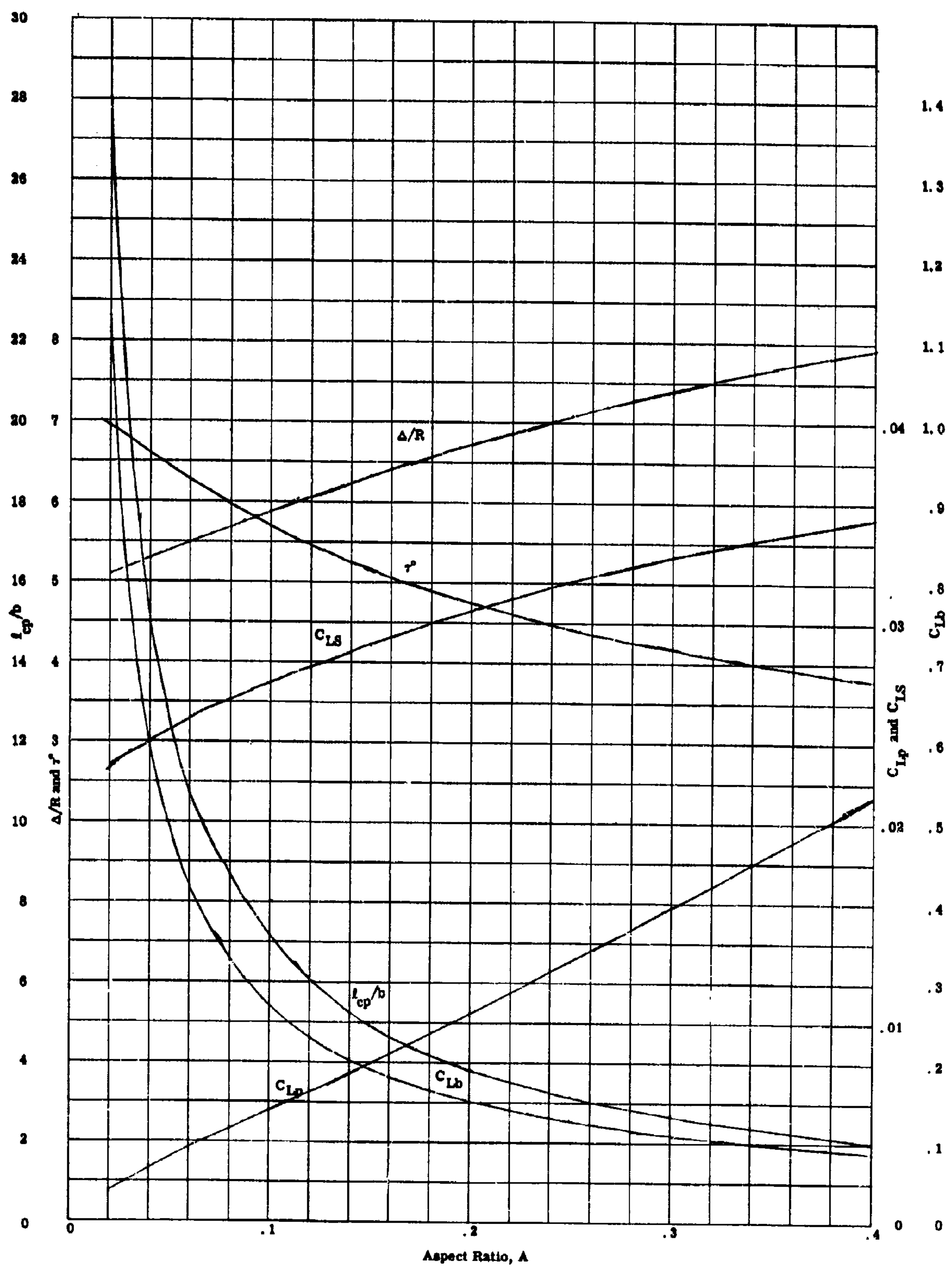
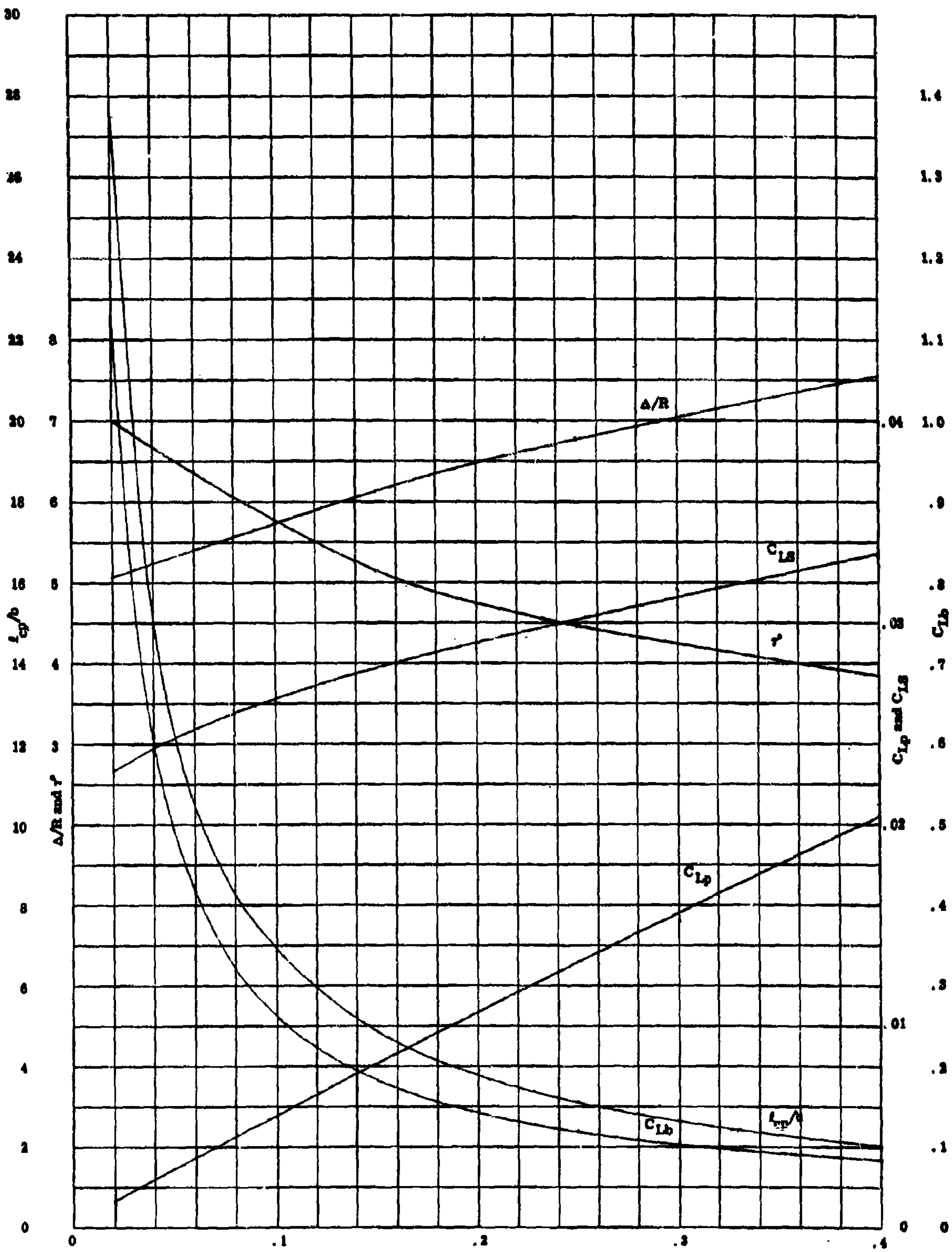


Figure 8 - Calculated Values of Aspect Ratio, Trim, and Hydrodynamic Drag for Three Planing Catamarans and One Conventional Planing Boat



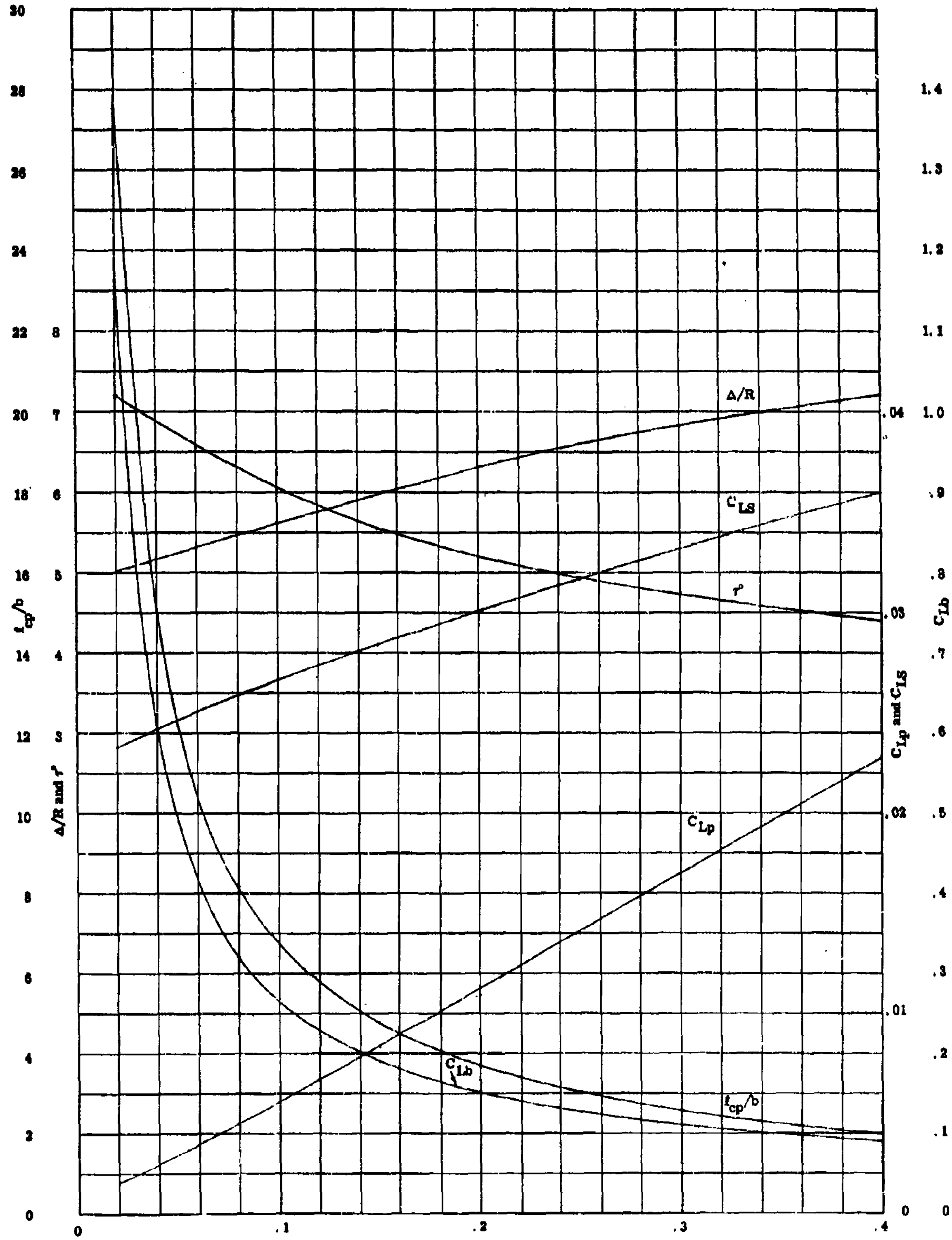
(a) $\beta = 0°$

Figure 9 - Optimum Values of Lift/Drag (Δ/R) for Planing Hulls of Low Aspect Ratio, and the Corresponding Values of τ, C_{Lb}, C_{Lp}, ℓ_{cp}/b, and C_{LS}



(b) $\beta = 5°$

Figure 9 (continued) - Optimum Values of Lift/Drag (Δ/R) for Planing Hulls of Low Aspect Ratio, and the Corresponding Values of τ, C_{Lb}, ℓ_{cp}/b, and C_{LS}



(c) $\beta = 10°$

Figure 9 (concluded) - Optimum Values of Lift/Drag (Δ/R) for Planing Hulls of Low Aspect Ratio, and the Corresponding Values of τ, C_{Lb}, ℓ_{cp}/b, and C_{LS}

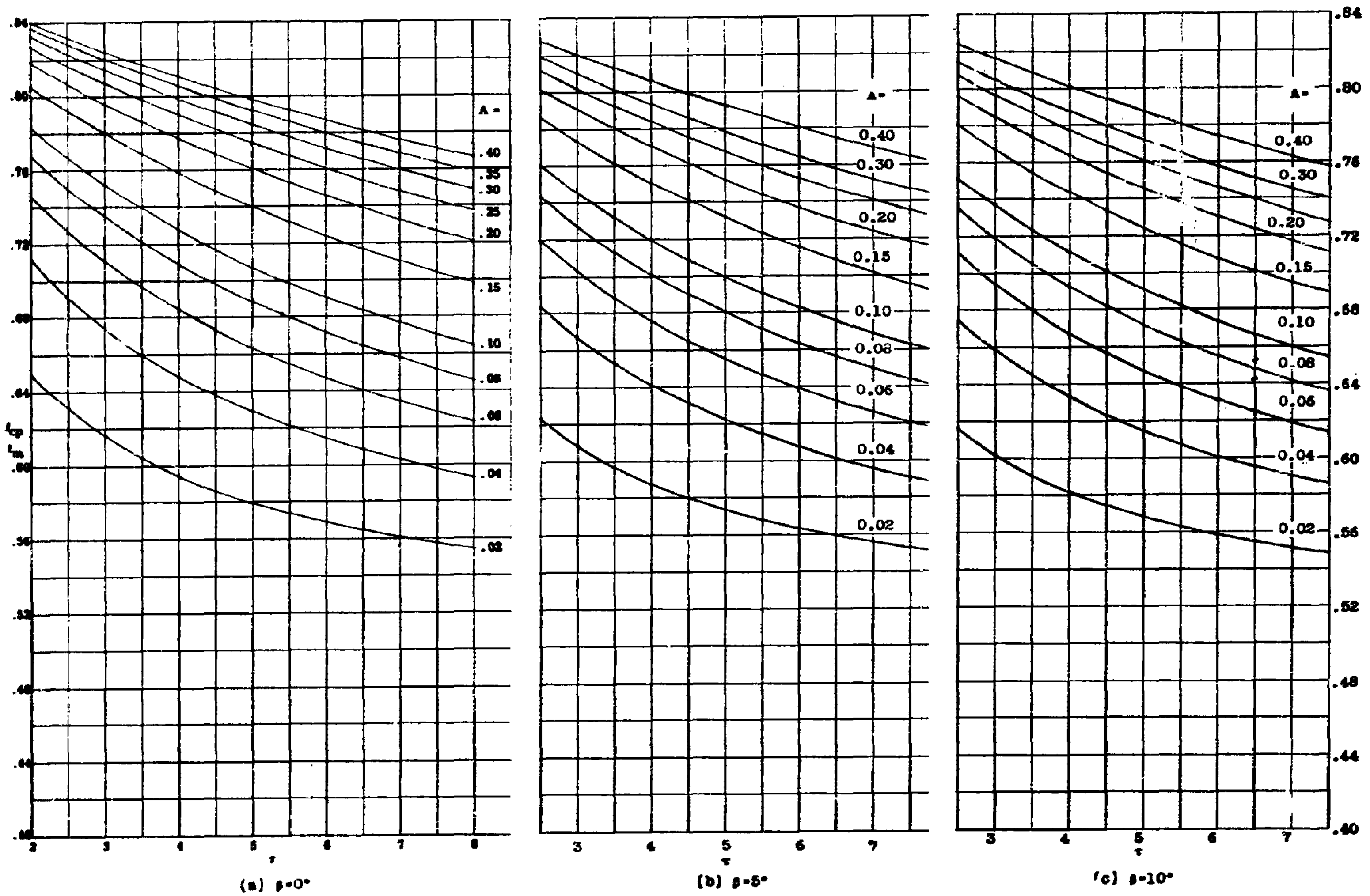


Figure 10 - Center-of-Pressure/Mean-Wetted-Length Ratio Versus Trim Angle

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1 Chance Vought Corp
Dallas, Texas

1 Douglas Aircraft Co., Inc.
Santa Monica, Calif

1 Edo Corp
College Point, New York

1 Hughes Fullerton Res & Dev
Fullerton, Calif

1 The Martin Company
Baltimore, Maryland
Attn: Mr. John D. Pierson

1 Curtiss-Wright Corp
Wood-Ridge, N. J.
Attn: Mr. Raymond F. Schaefer

1 Mr. Joseph G. Koelbel, Jr.
Massepequa, New Y[illegible]

1 Mr. Lindsay Lord
Falmouth Foreside 100, Me.

1 Mr. J.F. Stoltz
LaGrange, Ill.

1 Mr. Robert G. Mun[illegible]
Cocoa Beach, Fla

1 CDR Peter DuCane
Vosper Ltd
Portsmouth, England

1 Mr. Douglas Phillips-Birt
Lymington, Hants, England

1 Mr. Rodney Warrington Smyth
Falmouth, Cornwall, England

1 Senor Fernando Lagos Carsi
Lopez Mora, 75
Vigo, Spain

1 Mr. Juan Baader
Buenos Aires, Argentina

1 Ing. Pier G. Majoli
Sansepolcro, Italy

1 SARO (Anglesey), Ltd
Beaumaris, England

1 Fluid Dynamics Laboratories
Saunders-Roe Ltd
Isle of Wight, England

1 British Shipbldg Res Assoc
London W.1, England

10 ASTIA

8 ALUSNA, London

1 Rohr Aircraft Corp. Chula Vista, Calif., Attn: Mr. Harry R. Clements

David Taylor Model Basin. Report 1573.
GRAPHS FOR PREDICTING THE IDEAL HIGH-SPEED RESISTANCE OF PLANING CATAMARANS, by Eugene P. Clement. Nov 1961. iii, 33p. illus., graphs, refs. UNCLASSIFIED

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2. Catamarans--Resistance--Graphical analysis
I. Clement, Eugene P.
II. National Aeronautics and Space Administration
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